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FUSIBILITY DIAGRAM OF THE Ti-Cr-Mo SYSTEM

-USSR-

Following is a translation of the article "Diagramma plavkosti sistemy Ti-Cr-Mo" (English Version above) by N. B. Grum-Grzhimaylo and V. G. Gromova in Doklady instituta metallurgii imeni A. A. Baykov (Works of the Institute of Metallurgy imeni A. A. Baykov), No. 5, Production Metallurgy, Physical Metallurgy and Physicochemical Methods of Research, Moscow, 1960, pages 145-150.

A characteristic peculiarity of the components of the triple Ti-Cr-Mo system is their chemical activity at high temperatures. Metallic molybdenum, stable in air up to 400° , forms the oxide MoO_3 above 600° . Titanium possesses great affinity with oxygen and nitrogen. Interacting with them, it forms limited solid solutions and compounds. It follows from the phase diagram of Ti-O (1) and Ti-N (2) that oxygen and nitrogen considerably raise the temperature of the polymorphous $\alpha \rightarrow \beta$ conversion of titanium, expanding the area of existence of the α -phase. Hydrogen also dissolves in titanium, considerably lowering the temperature of its polymorphous conversion (3, 4).

The Ti-Cr system (Fig. 1, I) has been investigated by a number of authors (5-11). It has been established that in the primary crystallization process β -titanium and chromium form a continuous series of solid solutions. On the solidus curve a minimum melting point is observed for alloys with a content of about 50% Cr by weight. When the temperature is lowered, there is a decomposition of the solid solution with secretion of an intermetallic compound.

The question of the composition of the compound has been solved in different ways by various investigators (5-7). According to radiographic data (7) the compound corresponds to the formula TiCr_2 and has a cubic face-centered lattice of the MgCu_2 type with period $a = 6.929 \text{ \AA}$. Further investigations (12, 13) have revealed a high-temperature modification of the compound TiCr_2 with a lattice of the MgZn_2 type.

The high-temperature modification, having a hexagonal lattice ($a = 4.922 \text{ KX}$, $c = 7.945 \text{ KX}$, $c/a = 1.614$) exists above 1300° , while the low-temperature one with a cubic face-centered lattice ($a = 6.929 \text{ \AA}$) occurs at temperatures below 1000° . In the interval 1000 - 1300° the co-existence of the two modifications is possible.

In stabilizing the β -phase of titanium, chromium lowers the temperature of its polymorphous conversion. In the titanium-rich area of the Ti-Cr system a eutectoid conversion $\beta \rightleftharpoons \alpha + \text{TiCr}_2$ is observed. According to the data of (7) the eutectoid point is determined at 660° and 13 at. % Cr. The divergences in the temperature of the eutectoid conversion, the composition of the eutectoid point and the solubility of chromium in α -titanium at different temperatures are apparently to be explained by the different degrees of contamination of the alloys with oxygen and nitrogen, and are also, as shown in (14), the consequence of too slow a cooling of the alloys in hardening.

In the Ti-Mo system (Fig. 1, II (15-17) titanium and molybdenum form between each other a continuous series of solid solutions. Increasing the molybdenum content results in a continuous rise in the melting point of alloys. Molybdenum, like chromium, lowers the temperature of the polymorphous $\alpha \rightleftharpoons \beta$ conversion of titanium and increases the stability of the β -phase.

The solubility of molybdenum in the α -phase increases with decreasing temperature and does not exceed 0.8% at 600° ; at this temperature, the boundary between the phase areas $(\alpha + \beta)/\alpha$ runs near 28% Mo.

Radiographic investigations of alloys (17) hardened from 800° have shown that titanium increases the period of the molybdenum lattice, but no linear dependence of the period upon the composition is observed. In the radiographs of alloys with 60, 70, 80 and 90% Mo additional lines appear, the nature of which has not been ascertained by the authors. Because of the extreme slowness of the diffusion processes at temperatures below 600° the alloys of the Ti-Mo system have not been studied by the classic methods of physico-chemical analysis and consequently there is no certainty that no conversion takes place in the solid state at lower temperatures. As shown by a study of the Hall constant (18), the formation from the solid solutions of chemical compounds having the composition Ti_4Mo , Ti_3Mo or TiMo , is possible in the system.

In the Cr-Mo system (Fig. 1, III) (19-21) in the solid state the alloys form a continuous series of solid solutions. On the solidus line a minimum is observed at 1700° and a 25% Mo content. The melting point of chromium is 1770° . Investigation (22) has established the presence of a polymorphous conversion of chromium at 1830° , while the melting point of pure chromium is fixed at 1920° . With the presence of a polymorphous conversion in chromium, the phase diagram of Cr-Mo given in (21) cannot be regarded as complete, and additional investigations are required to refine it.

Work (23) gives data on the thermal analysis in the investigation of the Cr-Mo system. The results of the thermal analysis show that the minimum on the liquidus curve is observed at a higher temperature (1860°) and with a higher chromium content (about

80% by weight). In the solid state there are a number of points which are apparently connected with the conversion in the solid state. These data agree with earlier works (24).

The triple system Ti-Cr-Mo has not been sufficiently investigated. In (25) a limited area of alloys with a high titanium content has been studied in the temperature interval between 550 and 1300°. The phase boundaries have been determined by the parametric method (26), the application of which is favorable because of the presence of an extensive area of the β -phase. Characteristic of the Ti-Cr-Mo system in the titanium-rich area is the repression of the eutectoid reaction $\beta \rightleftharpoons \alpha + \text{TiCr}_2$ taking place in the dual system Ti-Cr, and the enlargement of the area of $\beta + \text{TiCr}_2$. The work gives the isothermal cross-sections at 600, 650 and 700°, the isotherms of the β -surface, the isotherms of the β ($\beta + \text{TiCr}_2$) surface and the vertical sections with contents of 4 and 8% Mo, 4 and 8% Cr and 90, 80 and 70% Ti. The solidus surface has been constructed the isotherms of the surface of incipient melting of the area investigated have been represented.

Works (27 and 28) are devoted to the study of the mechanical properties of various triple and quadruple alloys. The literature contains references to unpublished works (12) concerning the alloys of the Ti-Cr-Mo system.

It can be seen from a review of the literature that no complete investigation has been made of the triple system Ti-Cr-Mo. The present work is devoted to the study of the interaction of the components in the triple system Ti-Cr-Mo and the construction of a phase diagram of them.

The diagram of the fusibility of the system studied was investigated for 2 days; 5 days for the molybdenum base. Homogenization completely eliminated liquation in the composition.

The microstructure of the alloys was investigated after various regimes of thermal treatment. To ascertain the structure of the alloys of the triple system Ti-Cr-Mo from the aspect of the chromium and molybdenum angles, electrolytic etching was applied in 5% oxalic and 2% hydrofluoric acid, respectively. To etch the titanium-angle alloys a reagent of the following composition was used: 60 parts of glycerine + 20 parts of concentrated nitric acid + 20 parts of hydrofluoric acid.

Some characteristic microstructures of alloys are shown in Fig. 2. The alloy with 55% (by weight) Ti, 36% Cr and 9% Mo after hardening from 1200° has the structure of a solid titanium solution. The microstructure of the two-phase alloy consisting of a mixture of β -titanium and TiCr_2 is shown in Fig. 2, b. According to the X-ray analysis data, the TiCr_2 after hardening from 1200° is found in two modifications: cubic face-centered and hexagonal. Fig. 2, c, d, e, shows the microstructures of alloys which are one-phase after hardening from 1200°. In the alloy with

15% (by weight) Ti, 68% Cr and 17% Mo, decomposition of the solid chromium solution with secretion of $TiCr_2$ is observed after hardening from 900° (Fig. 2, f).

Table 1

① Вес по шихте, %			② Температура плавления, °C	③ Вес по шихте, %			④ Температура плавления, °C
Ti	Cr	Mo		Ti	Cr	Mo	
5	90	5	1835	40	40	20	1508
10	80	10	1812	40	30	30	1575
10	50	40	1865	40	20	40	1662
10	30	60	1905	40	10	50	1820
10	20	70	2100	50	40	10	1450
20	65	15	1670	50	30	20	1520
20	50	30	1675	50	20	30	1615
20	40	40	1745	50	10	40	1695
20	35	45	1825	60	30	10	1480
20	30	50	1825	60	20	20	1585
20	20	60	1900	60	10	30	1687
20	10	70	2120	70	25	5	1503
30	60	10	1553	70	15	15	1585
30	50	20	1575	70	5	25	1713
30	40	30	1627	80	15	5	1548
30	30	40	1670	80	10	10	1620
30	20	50	1780	80	5	15	1680
30	10	60	1878	85	10	5	1615
40	50	10	1460	85	5	10	1685
				90	5	5	1670

Legend: 1. Weight by charge, % 2. Melting point °C
3. Weight by charge, % 4. Melting point °C

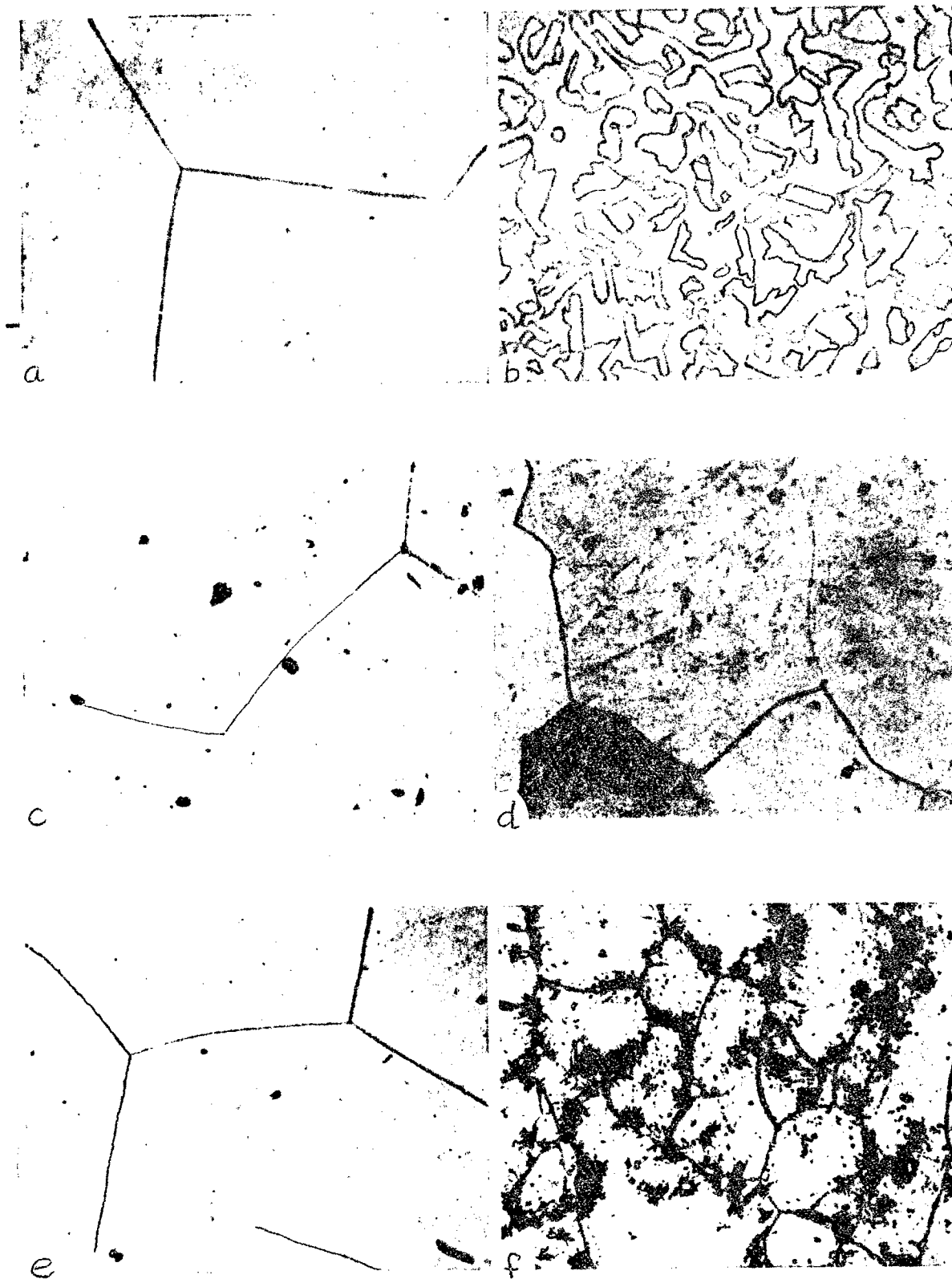


Figure 2

CONCLUSIONS

1. The solidus surface of the Ti-Cr-Mo is constructed; the solidus surface corresponds to the formation of a continuous series of solid solutions.
2. The decomposition of the solid solutions with secretion of the chemical compound TiCr_2 , which takes place in the dual system Ti-Cr, is also observed in the triple system Ti-Cr-Mo.

Fig. 2. Microstructures of the alloys of the system (x200).
(all percentages by weight)

- a. 55% Ti, 36% Cr, 9% Mo, hardened from 1200° , solid solution of β -titanium;
- b. 40% Ti, 50% Cr, 10% Mo, hardened from 1200° , β -titanium and TiCr_2 ;
- c. 15% Ti, 68% Cr, 17% Mo, hardened from 1200° , solid solution of chromium;
- d. 40% Ti, 20% Cr, 40% Mo, hardened from 1200° , solid solution;
- e. 10% Ti, 10% Cr, 80% Mo, hardened from 1200° , solid solution of molybdenum;
- f. 15% Ti, 68% Cr, 17% Mo, hardened from 900° , decomposition of solid chromium solution with secretion of TiCr_2 .

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